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To: Dr. D. Mills
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QUALIFYING AN IMPULSE DIGITIZER FOR MEASUREMENTS IN HV IMPULSE TESTS

J. Kuffel

Over the last several years high-speed digital recorders have come into widespread use for the measurement of fast transients. Performance specifications for digital recorders differ from those given for analog recorders. Consequently, the test procedures used to assess digital and analog recorders are not the same. Definitions of the specification terminology and test procedures for general purpose digital recorders are given in IEEE Standard 1057, "Trail-Use Standard for Digitizing Waveform Recorders." Our specific application of digital recorders lies in the area of high voltage impulse testing. Performance requirements for recorders used in this application are laid out in IEEE Standard 1122, "Digital Recorders for Measurements in High Voltage Impulse Tests." This report explains the rationale behind the development of these requirements and gives details of how a recorder can be tested for compliance.

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Abstract:

Working groups of the International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronics Engineers Inc. (IEEE) are presently engaged in preparing a standard on digital recorders for measurement in HV impulse tests. This paper shows how the main tests described in the proposed standard can be applied towards qualifying an impulse digitizer for HV Impulse measurements. Experimental results from the application of these techniques to different digitizers are presented. A major problem in using digital recorders in HV laboratories is electromagnetic interference. Previous low frequency measurements have indicated that high frequencies can be a problem and this paper reports some measurements at high frequencies. The consequences of these measurements for electromagnetic compatibility are discussed.

KEYWORDS: High Voltage Impulse Testing, Digital Recorders, Digitizers, Impulse Measurements.

1. INTRODUCTION

Over the past decade considerable work has been performed on the application of digitizers to measurement in HV impulse tests and many laboratories are presently using digitizers to record HV tests. The present standards on HV measurements make no explicit provision for the use of digital recorders and there is an urgent need to provide the necessary characteristics, calibrations and tests required to qualify a digitizer for recording HV tests.

IEC Technical Committee 42, "High Voltage Test Techniques," formally approved the formation of a working group to prepare a standard on digital recorders for measurements in HV Impulse Tests at its meeting in Montreal in March 1985. The following year the IEEE authorized a project on the same topic. An initial draft based on references[1-4] and on the results of research over the past decade was circulated to both working groups. From the outset there has been close liaison between the two committees and it has been agreed that each committee would try to provide its parent organization with standards which were technically and substantially the same. This goal has been achieved in the document now circulating to the National Committees of the IEC and the document which has been approved by the Power System Instrumentation and Measurement Committee of the IEEE Power Engineering Society.

A major difference between an oscillogram and a digital record is that the latter has a non-linear character which is introduced by the acts of sampling and quantization. Imperfections in the practical implementation of sampling and quantization will lead to increased non-linearities. The approach taken in the proposed standard is to limit these non-linearities to values which are sufficiently small that the digitizer can be treated as a quasi-linear device. In addition, resolution and sampling rates are specified to ensure that the impulse digitizer's resolution is as good as, or better than, that of the best available impulse oscilloscopes. Impulse digitizers are required to meet the accuracy requirements (2% in amplitude measurements and 4% in time measurements [4(c)]) without any signal processing of the raw data. If these requirements are met, then signal processing is permitted to enhance the reading accuracy. However, the raw data must be retained and used to evaluate the validity of the processing. This approach is very stringent but is justified on two counts: (1) that a stringent approach will assist in the acceptance of impulse digitizers and (2) that reasonably priced but high quality digitizers which meet these stringent requirements are now available from several manufacturers.

With one addition, the treatment outlined in this paper follows the conventional approach for selection and qualification of surge oscilloscopes. Initial selection is made on the basis of the nominal characteristics, then the low frequency or dc performance is measured accurately and then the degradation of performance for fast pulses is checked to ensure that the impulse digitizer can be used to record the fastest impulse of interest.

The addition is in the introduction of the concept of impulse scale factor which allows a systematic error of high resolution digitizers to be corrected by direct calibration. This technique is described in more detail in Section 4.

From the user point of view, another difference between surge oscilloscopes and digitizers (or general purpose oscilloscopes) is that surge oscilloscopes have passive input networks while digitizers (and general purpose oscilloscopes) usually have input amplifiers. Such amplifiers may be subject to drift in the offset and variations in the gain. While many digitizers are very stable and some even have the capability for automatic self calibration, others are sufficiently unstable that frequent calibration against an external reference is needed. The proposed standard requires calibration at every impulse which is in agreement with the recommendations of reference 2.

2. SELECTION OF NOMINAL CHARACTERISTICS

A digital recorder stores waveforms as a record of points characterized by discrete values of amplitude and time. The sampling rate and resolution are basic characteristics of a digitizer, as they determine the size of the recording errors inherent in the analog-to-digital conversion process. In other words, the sampling rate and resolution of a digitizer define the magnitudes of the errors which could be present even if the digitizer was to operate in an

ideal fashion.

The error due to quantization is uniformly distributed between plus and minus one half a code bin width (the code bin width is equal to the full scale value divided by 2^N where N is the number of bits resolution). For 8 bit and 10 bit digitizers, this corresponds to maximum possible errors of 0.39% and 0.1% of the full scale value (fsv) of each digitizer respectively.

The effects of discrete time sampling are most easily demonstrated with reference to the recording of sinusoidal signals. When recording the single cycle of a sine wave shown in Figure 1 it is obvious that in the evaluation of the sinusoid's amplitude the maximum discrete time sampling error is encountered when adjacent samples fall symmetrically on either side of the peak. The maximum error is shown in the figure for the cases of 16, 8, and 4 samples per cycle. The value of the maximum possible error is given by

$$1-\cos(\Pi * f * t_s) \qquad (1)$$

where f and t_s are the frequency of the recorded sinusoid and the digitizer's sampling interval respectively.

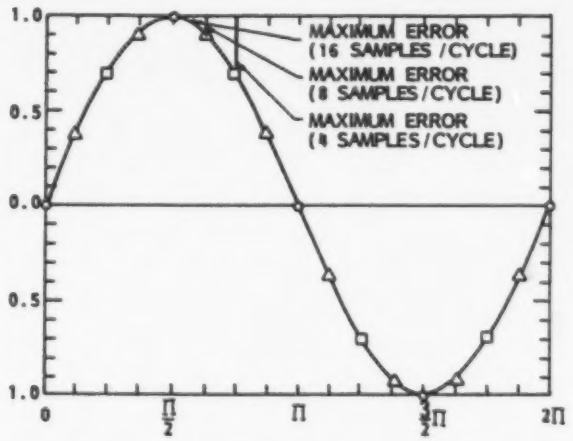


Figure 1

Sampling error for a sinusoidal input signal

In the practical realization of a digital recorder further errors are introduced. These consist of both systematic and random errors. The systematic errors can often be reduced by a correction, determined by calibration, but the random error introduces a non-linear component which cannot be corrected. The nature, limits, and consequences of the random errors encountered in digital impulse recorders vary depending on the instrument's design. As a result of this the determination of the suitability of a particular type of digitizer must consist of two stages. The initial stage consists of specifying what sampling rate and resolution are required based on the assumption that the digitizer behaves ideally. Following this, the dynamic performance of the digitizer under consideration must be checked. The former requires that the digitizer's nominal resolution in bits and sampling rate be related to the accuracies specified for instruments commonly used in high voltage testing. The latter covers the assessment of the instrument's dynamic errors through performance testing of the digitizer under consideration.

High Voltage impulse testing is performed on both self-restoring and non-self-restoring insulation. Depending on the type of insulation under test different requirements are put on the recording instruments. For tests on self restoring insulation the required instrument accuracy is specified in IEEE Standard 4, "Standard Techniques for High Voltage Testing", as 2% for crest values and 4% for time intervals.

In order to ensure that the time parameters of impulses can be measured within the required accuracy, the selected sample rate must be sufficiently high. The shortest time interval to be measured to determine the shape of standard impulses is 500 ns. This limit is the same for full and standard chopped impulses (the time from 30% to 90% of the shortest permitted front time (840 ns) is 504 ns and the shortest time-to-chop which is covered by the present standards is 500 ns). The full permitted uncertainty allocated to the recording device is 4%. On a base of 500 ns this is equal to 20 ns which corresponds to a minimum sampling rate of 50 million samples per second. In many digitizers the samples are taken at very uniform and accurately known time intervals and for these digitizers the only significant uncertainty in the measurement of a time interval will be one sampling period. In some digitizers, such as scan converters, the timing is less precise and must be calibrated. This calibration can reduce the inaccuracy of the measurement of a time interval but the calibration itself has an uncertainty of one sampling period. With such digitizers the total uncertainty may be as high as two sample periods since in the worst case the errors in the impulse measurement and the calibration may add. In consequence a sampling rate of 100 million samples per second is needed to ensure adequate resolution. However, scan converters usually offer very high sampling rates since they are designed to record very fast transients.

A minimum limit of 60 million samples per second is sufficiently high to adequately limit the uncertainty of most commercially-available clock-controlled digitizers to less than 20 ns. When measuring other time parameters this requirement can be generalized as:

$$\text{Sampling Rate} > 30/T_X$$

where T_X is the time interval to be measured.

In addition to measuring the time parameters of an impulse it is necessary to be able to measure the peak voltage to within a given accuracy and to reproduce any oscillations that may be superimposed on the impulse. The required accuracy of 2% in the measurement of the peak voltage for full lightning impulses and impulses chopped on the tail is easily exceeded with a digitizer resolution of 7 or more bits. In this case the predominant source of error contributed by the digitizer is the quantization error as there are no sudden changes in the waveform in the vicinity of its peak. For impulses chopped on the front the most demanding situation covered by the standards specifies that the peak voltage of an impulse with a time-to-chop of 500 ns be recorded with the recording device contributing an error of less than 2%. In this situation, the discrete time sampling error must be considered as well as the quantization error. For an ideal sawtooth input the maximum possible error is given by the product of the sampling interval and the signal's rate of rise (Figure 2). For a duration of 500 ns, sampling at the minimum acceptable rate set by the requirement for time interval measurement could result in an error as high as 4%. In contrast to the case of an ideal

sawtooth waveform, high voltage impulses are rounded at the chop. Figure 3 shows an example of a linearly-rising impulse applied to a 250 mm sphere gap with a gap length of 60 mm. The impulse was measured using a small divider insulated by compressed gas. The rate of rise of 10.8 kV/ns and time-to-chop of 36 ns are much more severe than the standard test impulses. However even in this very severe case the waveshape shows that the slope close to the chop is very much less than the average rate of rise from 50 to 90% of the breakdown voltage. For larger breakdown distances and larger (and hence slower) impulse measuring systems the effect will be more pronounced and the requirements on sampling rate provided by the standard for time interval measurements will be sufficient to ensure that the contribution of sampling rate to the overall error in breakdown voltage measurements is negligible.

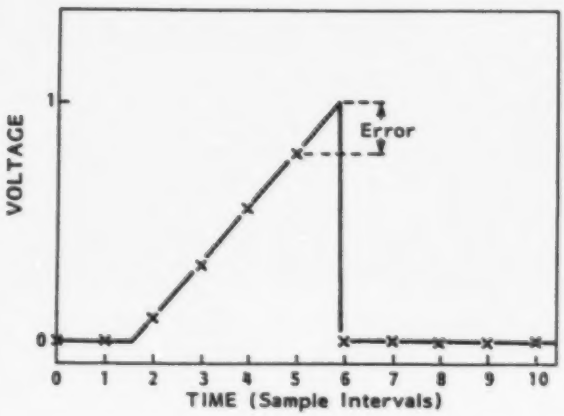


Figure 2

Sampling error for an ideal sawtooth input signal

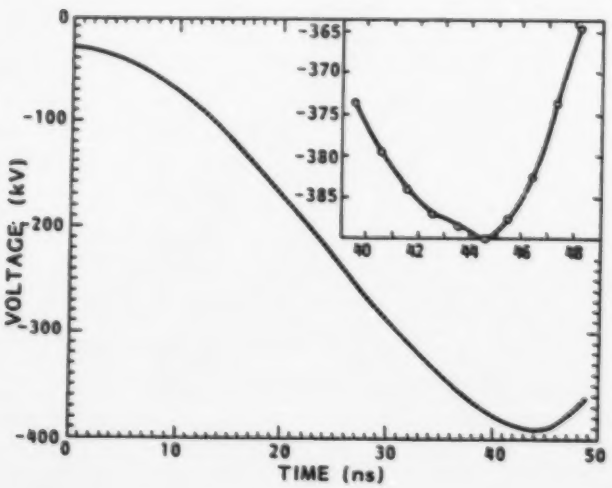


Figure 3

Actual record of a linearly-rising front-chopped HV impulse (Inset shows every fifth sample in the vicinity of the chop)

Another criterion that must be met with regards to amplitude measurements of impulses is that oscillations superimposed on the impulse front must be reproduced. The analysis below indicates that this requirement sets the most stringent limit on the minimum sampling rate, even more stringent than that required to ensure an error of less than 2% in the peak measurement of the fastest front-chopped lightning impulses. The highest possible frequency (f_{max}) at which such oscillations can occur is given in [4(c)], in terms of the dimensions of the impulse generating circuit. Reference [2] specifies that the upper cutoff frequency (3dB) for surge oscilloscopes must be at least 2 f_{max} and this is also a necessary condition for the analog circuits of the digitizer. Too low a sampling rate may give discrete time sampling errors which result in an apparent attenuation of an input sinusoid. When there are four samples per cycle the maximum possible error in amplitude measurement is 29.3% (from (1)) which is equivalent to an apparent attenuation of 3dB. Hence, the sampling rate must be at least twice this, i.e. eight times f_{max} which ensures the apparent attenuation is less than 8% at f_{max}. A summary of the values of f_{max} possible in some HV impulse generating circuits is given in Table I. The table also contains the minimum sampling rate necessary to ensure that the maximum apparent attenuation is less than that specified in reference 4a.

Table I

Values of f_{max} and Minimum Required Sampling Rates for Various HV Impulse Generating Circuits

SAMPLING RATE ERRORS FOR AMPLITUDE MEASUREMENTS AT f_{MAX}			
RATING OF GENERATOR (MV)	HEIGHT (m) (TYPICAL)	f_{MAX} (MHz)	MINIMUM SAMPLING RATE (MHz)
3	10	3.75	30
2	7.5	5	40
1	4	9.375	75
0.5	2.5	15	120

Some HV tests on non-self-restoring insulation call for a comparison of the records of two impulses rather than a precise measurement of their magnitude. For these tests high resolution is required in order to reveal any minute differences between the records being compared. Until recently the only instruments suitable for these tests were analog impulse oscilloscopes whose resolution attained 0.3% fsv at best. Slightly better resolution can be attained by a 9 bit digitizer which has a resolution of 0.2% fsv. These comparative tests entail recording oscillatory transients with components up to 3 MHz. This imposes a requirement for a sampling ratio of at least 24 million samples per second.

3. DC CALIBRATION

Users of surge oscilloscopes may measure the integral non-linearity by applying several (typically 10) equally-spaced dc voltages. Routine calibration should be performed with every impulse using three voltages viz zero and two levels which span the crest value of the impulse i.e. one above and one below the crest value. Because of the discrete resolution and high stability of many digitizers it is possible and useful to perform a much more detailed calibration.

The input/output relationship or quantization characteristic of an ideal digitizer is a stairway of vertical risers (the code transition thresholds) and horizontal treads (the code bins) (Figure 4). The line AB goes through the mid-points of the code bins and the inverse of its slope gives the static scale factor. The quantization characteristic can be measured as follows. A low dc voltage is applied to the instrument and a record of the output is taken. The dc voltage is incremented by a small step and another record taken. Enough records are taken to span the full scale range. A step size of a tenth of the average code bin width will allow the code bin to be located with an uncertainty which is negligible compared to the average code bin width. There is no problem with the evaluation of a record because every sample in a particular record will have the same code.

However, real digitizers will not return such simple results. Noise may cause each record (or some of the records) to have more than one code and a decision has to be made on how to evaluate such records. The recommended method in the proposed standard is to use the average value of the record. This approach will give a quantization characteristic with inclined risers and treads when the noise is small compared with the average code bin width. When noise contributes to the uncertainty the use of 10 steps per code bin width may not be justified. However, at least 4 steps per code bin width must be used (Figure 4).

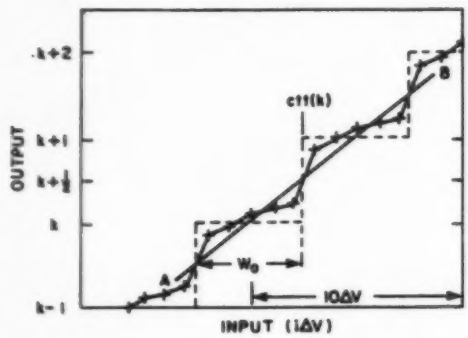
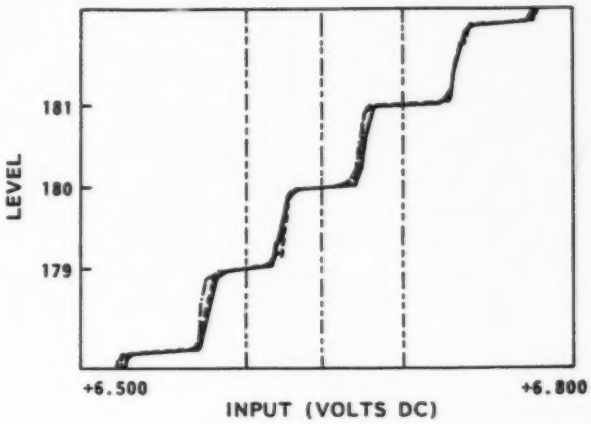


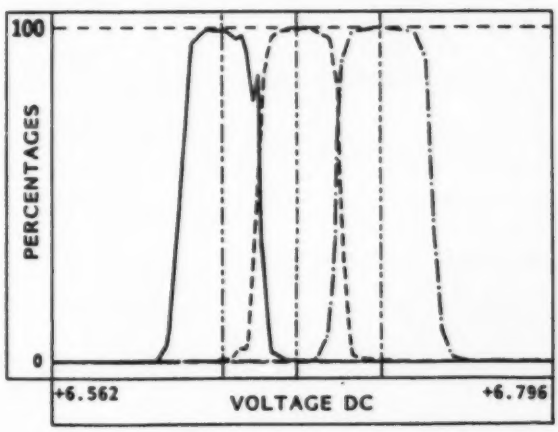
Figure 4

Four codes of a quantization characteristic. Dashed curve is for an ideal digitizer whose average code bin width is w_0. The code transition threshold from code k to k+1 is marked (ctt(k)). Simulations of measured points are shown as +.

Measured quantization characteristics taken using ten steps per code bin width are shown in Figures 5 and 6. Figure 5a shows a quantization characteristic obtained during the dc calibration of an 8 bit digitizer. The three traces represent the results of three calibrations. The code profile of level k can be plotted as the number of occurences of level k in each record against the input voltage for that record. Three code profiles as obtained from these calibrations are given in Figure 5b. When the noise is large the quantization characteristic based on the average value will degenerate into an approximate straight line perturbed by noise. An example of this is presented in Figure 6a which shows the results of a calibration on a 10 bit digitizer. The noise, whose magnitude is in the same range as the quantization steps, causes the quantization characteristic to appear as a straight line. The effect of reducing the noise relative to the quantization step size can be illustrated by increasing the quantization step size, i.e. treating the 10 bit digitizer as having a poorer resolution. This is done by pairing adjacent levels for an effective resolution of 9 bits. Similarly a resolution of 8 bits can be achieved by summing every four adjacent levels into one. An example of one of the code profiles used in constructing the three quantization characteristics is shown in Figure 6b. As can be seen from Figure 6a as the relative magnitude of the noise is decreased (i.e. the digitizer's effective resolution is decreased from 10, to 9, and then to 8 bits) the quanitization characteristic becomes progressively more similar to that of an ideal digitizer.



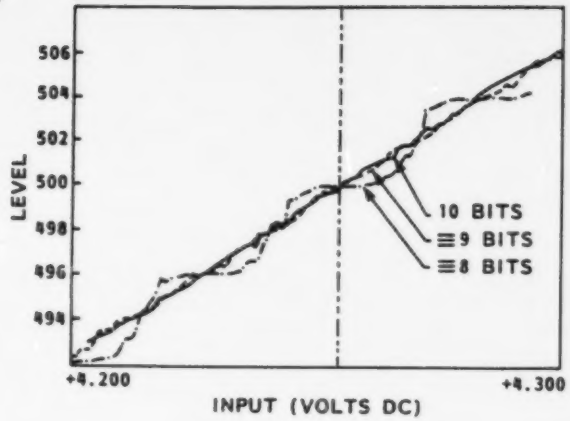
(a) Comparison of quantization characteristics obtained from three dc calibrations



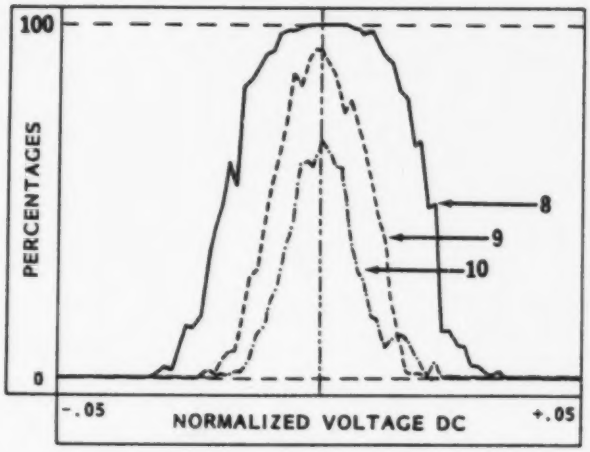
(b) Three code profiles obtained from dc calibration

Figure 5

DC calibration of an 8 bit digitizer



(a) Quantization characteristics obtained by treating the digitizer as having 10, 9, and 8 bit resolution



(b) Code profiles obtained when the digitizer is treated as having 10, 9, and 8 bit resolution

Figure 6

DC calibration of a 10 bit recorder

4. MEASUREMENT OF THE IMPULSE SCALE FACTOR

When a voltage step is applied to an impulse digitizer the response may settle quickly to the final level or it may have two time constants, a short one typifying the response of the input circuit and a much longer one indicating thermal effects (Figure 7). Even in the latter case the impulse digitizer may still be used if the response is constant over a sufficiently long time interval (the appropriate time intervals for each impulse are defined in the standard). Either of two approaches may be used: (1) the step response is taken using an accurately-known step. From this the interval(s) over which the response is sufficiently constant is (are) determined. The scale factor(s) is (are) determined for each interval from the settling level in that interval.

(2) the step response is used to determine the interval(s) over which the response is sufficiently constant and the impulse scale factor is measured using pulse calibration. This new test, using pulse calibration which takes advantage of the ease of reading digital records and also permits simultaneous calibration of both amplitude and time scales, has also been proposed as the recommended routine test of an impulse digitizer.

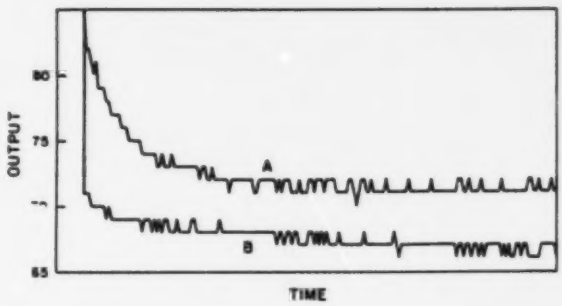


Figure 7

Settling level of the step response of a 10 bit digitizer. DC level before chop, 975. Curve A on 10 us sweep, Curve B on 100 ms sweep.

A stable generator of precise calibration pulses, whose waveshapes are chosen from those specified in the standard according to the type of impulse to be measured, is required. Suitable generators of pulses at levels up to 10 V are presently available (e.g. stable electronic pulse generators or arbitrary waveform generators) and higher voltage pulsers are being developed by several manufacturers. The accuracy and stability of these pulsers should be traceable to National Standards in the same manner as other calibration equipment. By applying such a pulse the impulse scale factor and time scale factor can be verified directly under dynamic conditions which are equivalent to the impulse. A comparison of dc and pulse calibration of a 10 bit digitizer (Figure 8) shows the same difference between impulse calibration and dc calibration as is visible in Figure 7 between curves A and B. This difference appears to be typical of high resolution digitizers and makes direct measurement of the scale factor under pulse conditions essential.

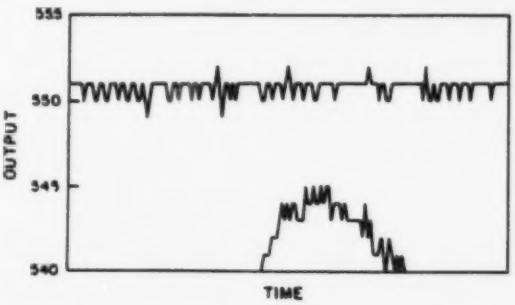


Figure 8

Comparison of pulse and dc calibration. Pulse amplitude 9.669 V (measured by slideback). DC level 9.66900 V.

5. DIFFERENTIAL NON-LINEARITY (dnl)

A digitizer allocates a digital code to a small range of the analog input voltage. This range is called the code bin width (Figure 4). Ideally all code bins should have the same width which is the full scale value of the input voltage divided by the number of code bins. In practice not all code bin widths will be equal. The deviation of a particular code bin width from the average code bin width, divided by the average code bin width, is the differential non-linearity (dnl) of that code bin. The dnl under dc conditions can be calculated from the dc calibration. However, at very high rates of change of input, the dnl may increase drastically and in many digitizers this sudden increase in dnl sets the high frequency limit of the digitizer. This increase is caused by limited performance of the digitizer's components, in particular inadequate (slow) response and settling characteristics. It is necessary to ensure that this effect does not reduce the accuracy of the digitizer to less than 2% fsv. This can be done by recording the dnl for various signal slopes.

Rather than attempting to measure the code transition thresholds at high rates of change of the input voltage the dnl can be inferred from the statistical distribution of a large number of records of any known signal. The signal recommended in the proposed standards is a triangular wave. When recording an ideal triangular wave, whose repetition frequency is not harmonically related to the clock frequency, each code of an ideal digitizer occurs with equal probability and the distribution of occurrences of the codes is uniform. The development of the histogram for this case is illustrated in Figure 9.

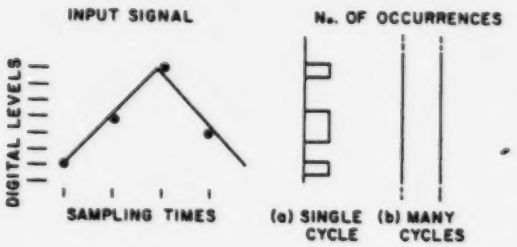


Figure 9

Development of the histogram used to quantify dnl

In practice, a large number of cycles of a nearly-triangular signal are recorded and the records are sorted by code to give an occurrence histogram. If a particular code bin is narrower than the average then this code will occur less often and will appear as a "hole" in the histogram. If a particular code bin is wider than the average then it will occur more often and will appear as a "chimney" in the histogram. A measured histogram is shown in Figure 10 showing "holes" and "chimneys".

As the dnl increases some code bins will become very narrow and occur very rarely. Ultimately such codes may not occur at all and have an effective width of zero. When this happens such codes are referred to as missing codes.

Non-linearities in the input test signal will also appear in the recorded histogram and hence these non-linearities should be small relative to the required dnl.

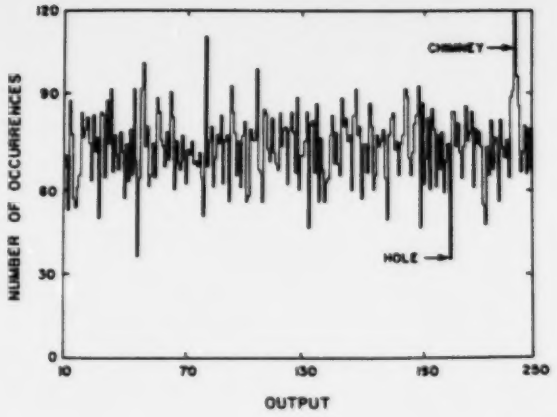


Figure 10

Histogram obtained in the evaluation of the dnl of an 8 bit digitizer

Referring to the definition of dnl it can be seen that an ideal digitizer will have a dnl of 0 as the width of every code bin is equal. If a digitizer is ideal except for one code which is missing while the two adjacent codes are 50% wider than the average then the dnl of the missing code is -1 and the dnl of each of the two adjacent codes is 0.5 (Figure 11). The effect of this is to reduce the resolution of the digitizer by 50% at the missing code. The proposed standard specifies that the dnl should be within +/-0.8 which requires that the width of the widest level be less than 1.8 times the average code width (w_o) and the width of the narrowest be greater than $0.2w_o$. If the width of a code bin is increased symmetrically about its center level to give a dnl of $1.8w_o$ the resolution of the digitizer decreases to $+/-0.9w_o$ as compared to $+/-0.5w_o$ which is the resolution characterizing a digitizer with a dnl of zero. For an 8 bit digitizer a resolution of $+/-0.9w_o$ restricts any local aberrations in the scale factor to less than +/-0.36% fsd. (+/-0.9 x 0.4).

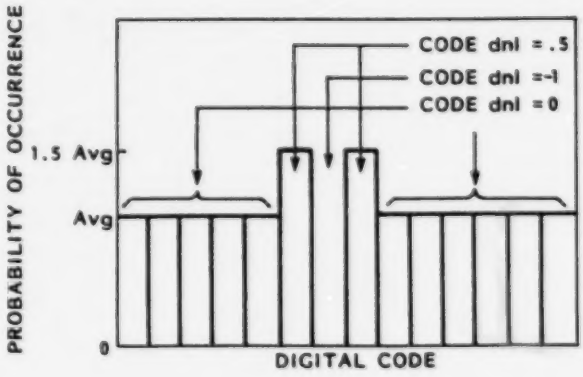


Figure 11

Illustration of dnl values

The variation of dnl with rate of change of input voltage using triangular and/or ramp inputs has been measured by several workers [5-7]. This work has shown that the dnl is approximately constant at low rates of rise of the input signal and increases rapidly above some critical rate of rise. Provided

the critical rate of rise of a digitizer is sufficiently high, the digitizer may be suitable for recording impulses. The proposed standard requires that the dnl is within +/-0.8 for signal slopes of up to fsv/(0.4*T_x) where T_x is the shortest time interval to be measured. For both the fastest permitted full lightning impulse and the shortest possible time-to-chop of front-chopped impulses this requires testing with a triangular wave whose amplitude is not less than 80% fsv and whose repetition frequency is about 3 MHz.

6. INTERFERENCE IN HV LABORATORIES

Digitizers (and general purpose oscilloscopes) are more sensitive to interference than surge oscilloscopes. Hence special precautions are needed to enable them to perform adequately in impulse recording and their performance under test conditions must be verified by an interference check as prescribed in[4]. However, it is desirable to have a test which can be used to test shielding, power conditioning and signal transmission techniques. Reference[2] specifies a test using a simple simulator to produce levels and frequencies of interference which were considered adequate. This prompted an inter-laboratory study of interference under different HV test conditions[8]. The result of this study showed that the simulator is usually adequate to check the compatibility of an impulse digitizer to interference generated in typical impulse tests of air gaps. However, the study also showed that more severe conditions and higher frequencies are sometimes generated. In particular sparkover in oil or gas and/or puncture of solid insulation can be expected to give higher levels and frequencies of interference. A modified simulator has been designed and tested.

A schematic of the original simulator is shown in Figure 12. It consists of a precharged HV capacitor, a sphere gap, and a long tubular conductor suspended above the laboratory ground plane. The digitizer under test is located under the simulator and its performance is monitored when the sphere gap breaks down and the capacitor is discharged into the tubular conductor. The simulator tube is open circuited or grounded at the end AB to induce a predominant electric or magnetic field respectively. The waveform, and hence the frequency spectrum of the transients produced by the simulator, is determined by the geometry of the circuit and the breakdown time of the sphere gap. In particular the latter limits high frequencies in the transient interference spectrum.

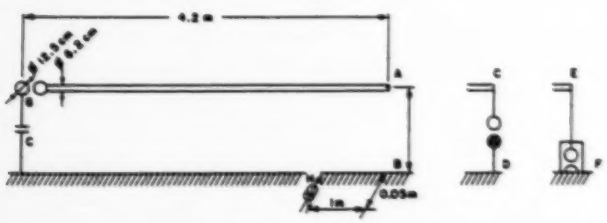


Figure 12

Simulator used for electromagnetic compatibility checks

The proposed modification is to replace the air gap by a pressurized gap (with a much shorter gap length). The higher pressure and the shorter gap both contribute to larger high frequency components. The performance of the modified simulator was measured using fast magnetic field probes and a fast recording system. The overall system bandwidth was 130 MHz. The frequency spectrum and time domain records are presented in Figure 13. The modified simulator adds an important enhancement of the high frequency spectral harmonics (10 to 100 MHz) which better represents the interference observed during impulse tests on solid or compressed gas insulation. Taking into account an unexpected breakdown of the test object or the impulse generator components it is recommended that the shielding of digitizers protect the instrument against such events. In order to assure efficient protection the shield should be examined with the use of the modified (pressurized gap) simulator.

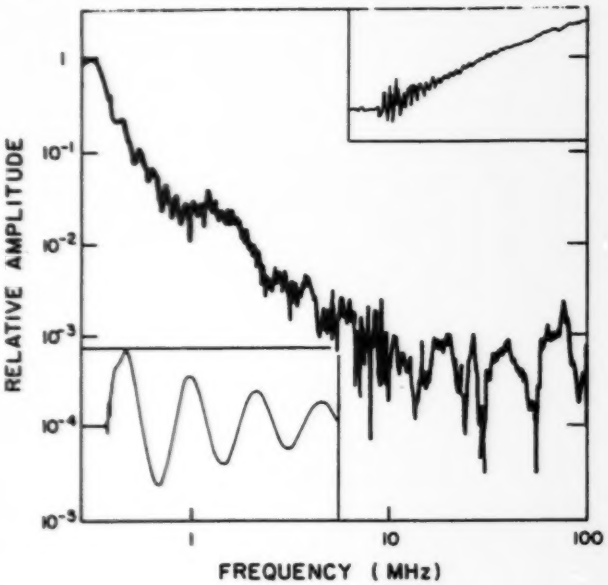


Figure 13

Emission spectrum of simulator with pressurized gap. Insert bottom left - time domain transient. Insert top right - expanded view of time domain transient.

7. PRECAUTIONS TO REDUCE INTERFERENCE

Interference may be induced by the electromagnetic field or conducted by either the signal or supply lines. Interference on the mains supply can be reduced by inserting an rf filter and an isolating transformer. Interference on the signal line is generally more difficult to eliminate. Adequate grounding and shielding must be combined to reduce interference. The effects of the cable shield have been studied by several workers (for example reference [9]) and it has been shown that the effectiveness of shielding depends strongly on the density of the shield. The general features of shield performance are shown in Figure 14. Open-weave shields where the physical coverage is only about 65% are comparatively poor while tighter weaves give better performance. Double shields and triaxial cables give much better performance while the best performance is given by metal tubing.

Most digitizers will need an additional shielding enclosure. A continuous metal shield is required to adequately reduce inductive coupling and the electromagnetic field radiated from the HV circuit.

In practical enclosures the continuity can be compromised by the seams of the enclosures, air inlets for cooling and cable feedthroughs. Special techniques, such as wire gaskets on doors and welded seams, are needed. However continuity at seams, especially at door seams, can be reduced by oxidation, dirt and grease. The effects of artificially reducing the continuity at the door seams of a galvanised steel box are shown in Figure 15. A receiving loop is mounted inside the box and a transmitting loop is mounted outside the box and the received spectra, between 2 and 10 MHz, for three conditions are plotted. Reducing the continuity at the door seams increases the amount of interference which penetrates the enclosure. Direct confirmation of this effect is provided in Figure 16 which shows a chopped impulse recorded with (A) the cabinet door open and (B) the cabinet door closed. Interference caused by the firing of the generator can be seen at the start of impulse A but this is not sufficient to affect the measurement. Interference caused by the firing of the chopping gap (pressurized, gap length 1mm) can be seen just prior to the chop and after the chop on impulse A and this interference would contribute to the error in the measurement of crest voltage. Closing the door eliminates the effects of both sources of interference.

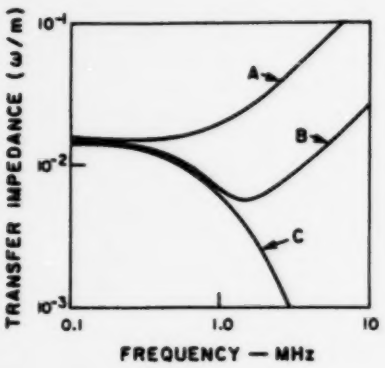


Figure 14

Comparison of the performance of various shields
A-Braided, single
B-Braided, double
C-Solid

A convenient approach which provides the required shielding with convenient access for operation is to use an enclosure consisting of two parts: one part with high shielding efficiency (completely enclosing the digitizer) which is required for real time recording of the impulse and the other part open to allow access to the computer, plotter, and printer which operate after the impulse. The open enclosure will provide shielding against capacitive coupling provided that the opening faces away from the sources.

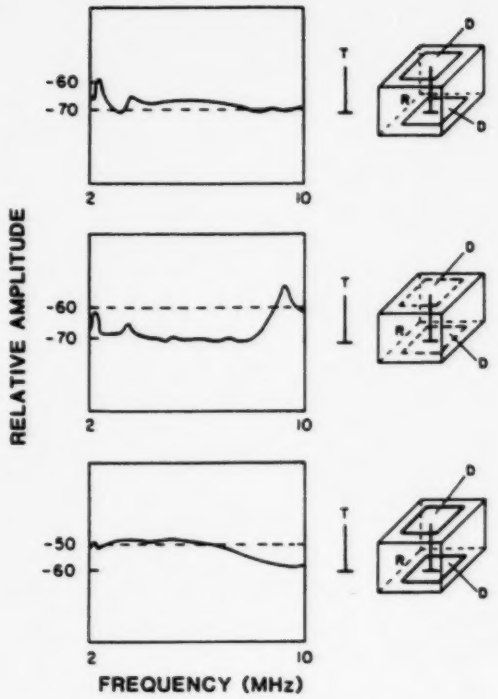


Figure 15

Shielding effectiveness
Top - door closed
Middle - door closed and paper in one half of the joint
Bottom - door closed and paper in all the joints.

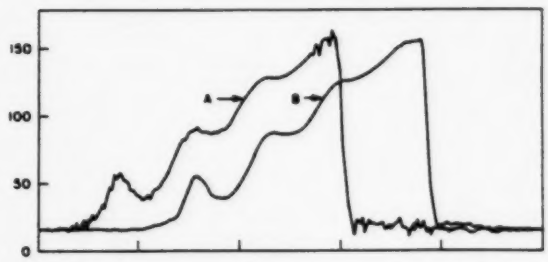


Figure 16

Record of a chopped impulse.
Curve A - door open; Curve B - door closed.

8. CONCLUSIONS

The performance tests forming the basis of the proposed standard on digital recorders for impulse measurements have been outlined and the importance of electromagnetic compatibility has been illustrated. The necessity of measuring the impulse scale factor has been shown. While this can be done by taking the step response using a step generator of known amplitude, it is more practical to use a special pulse generator (traceable to a national standard) since this provides both the amplitude scale factor and time calibration.

9. ACKNOWLEDGEMENTS

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